International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 8, Issue 6, Dec 2018, 545-554

APPLICATION OF THE TAGUCHI TECHNIQUE FOR WEDM PARAMETERS FOR TUNGSTEN CARBIDE

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ABSTRACT

In this paper the parametric response for wire electrical discharge machine (WEDM) for pure tungsten were processed to investigate. The relationships between material removal rate (MRR), a surface roughness (SR) and density of surface crack density (SCD), based on the process response were explore with the significance of machine variables parameters such as voltage (Vo), peak current (Ip) and wire speed (Ws). The experiment has been used L9 Taguchi array's design of experiment (DOE) to determining the effect of machine condition each of experiment were ensured successfully under statistic evaluated as the data result were investigated by analysis of variance (ANOVA). The result seems that an increase in discharge current and voltage could cause an increase in MRR, surface roughness and density of crack. The specimen was observed by scanning electron microscope using for investigating the surface response at separate conditions the characteristic of distribution crack length per area it was an optimized condition for the surface crack density. The methodology of Signal to noise ratio and ANOVA was used to analyze the main effect to processes response the result of research also identification parameters for cutting tungsten utility approach in the manufacturing process.

KEYWORDS: Tungsten Carbide, Wire-EDM, Taguchi Method, Material Removal Rate, Surface Roughness, a Surface Crack Density (SCD, & ANOVA

Received: Sep 15, 2018; **Accepted**: Oct 05, 2018; **Published**: Nov 24, 2018; **Paper Id.**: IJMPERDDEC201858

Original Article

1. INTRODUCTION

Wire electrical discharge machine (WEDM) is processing machinery widely used for parts that difficult to cutin industry (Dabade et al., 2016). WEDM was used to produce complex shapes with good accuracy and smooth surface, some researchers have developed different factors and optimize process parameters considering a large number of machine responses. The mechanism for WEDM depends on wire electrical conductivity and material using in the process(Singh et al., 2016) the electrical spark between wire electrode and materials under influence mainly "spark gap", occur short duration discharge get melt and remove the particle from work piece flushing by de-ionized water. The effect of machining process parameter such as voltage (Vo), discharge current (Ip), wire speed (Ws), pulse on-off time are correlations with the performance characteristic of surface integrity, material removal rate, surface crack density. The sinter group materials characteristic likely diamond is "Tungsten carbide (WC)" it has growing interest in the manufacturing industry, electronic lighting, cutting tool and present to varieties functions in part of component machine (Upadhyaya, 1998). The tungsten carbide is excellent in chemical and physical properties such as the high melting point at 3410 ± 20°C, high strength and hardness (Selcuk et al., 2013). tungsten (W) is a refractory metal and its structure is bcc (body-centered cubic) and cobalt (Co) is used for a

binder material, it is stable at the temperature at 400°C. Cobalt binder has a cubic lattice which cannot be transformed by annealing. However, it is due to the stabilization of the cubic modification by dissolved tungsten and carbon, the crystal structure phase of WC and Co is hexagonal structure(Upadhyaya, 1998). The microstructure of tungsten-cobalt, contains the hardness of tungsten carbide (WC) which is connected by an obligation of cobalt (Co) that can be structural of difference for 2 phases called skeleton as shown in Figure 1. (Jangra, Grover, & Aggarwal, 2012).

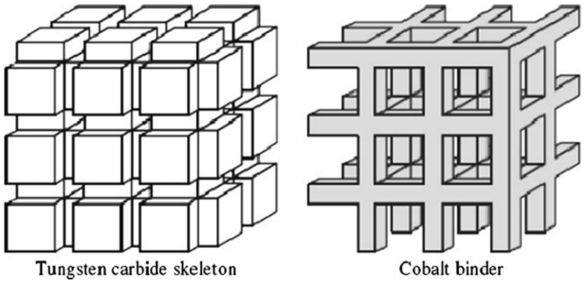


Figure 1: Structure of Tungsten Carbide and Cobalt Binder

Srivastava et al. (2016)found that the lowest surface roughness value can be obtained at2.214 micron when using WEDM; wire tension of 0.6 N, feed rate10 m/min, flushing pressure 3 kg/cm2 and 80A of current by Taguchi method. Chen et al., found that the finish cut on wire electrical discharge machining (WEDM) of tungsten carbide depends on the cutting speed. However, pure tungsten material is always embitter due to correlated thermal and mechanical properties with low temperature, it has an indicator of grain growth and leads to recrystallization and grain boundaries (GBs) occurs(Xie et al., 2018).

Hiong and Xiaoping (2003)studied current of EDM about micro cracks on tungsten surface, it is revealed that low melting point of cobalt causes the cobalt melt and first separate from the tungsten carbide matrix, resulting in microcracks and micropores appointed by the thermal stress during EDM process. Faleschini et. al.,(2007)used liquid nitrogen to reducing a temperature of tungsten alloy material and any other materials. When the temperature changes, as a result of various factors, such as the cooling of the workpiece size particles and substances of various heat quantity of impurity and the temperature rise is a result of stress during the operation leading to microcracks (Faleschini et al., 2007). The study for reducing microcrack and improving surface roughness for WC-Co was claimed that the process parameters are cutting speed and surface roughness respectively. Moreover, it was reported that discharge current and rate of flow dielectric fluid were inverse proportional to surface finish of WC-Co composites. (Jangra et al., 2012)

This paper aims to investigate the process parameters such as voltage (Vo), discharge current (Ip), wire speed (Ws) compared to performance characteristic of material removal rate, surface integrity, surface crack density on tungsten carbide using Taguchi method.

2. METHOD

2.1 Material and Equipment

In this study, the experiment was conducted on Mitsubishi FA10S wire electrical discharge machine (W-EDM) with de-ionized water based dielectric. The electrode material is a brass wire of 0.25 mm in diameter. The experiment was carried out on tungsten carbide(W73%C11%). The work piece was confirmed testing chemical component by EDS as shown in Figure 2and the chemical composition of tungsten carbide is shown in Table 1.

Figure 3 show experimental set up. The thickness of work piece is2.0 mm. The experiments were carried out by the maincut and trim cut using three parameters; voltage open(Vo), peak current (Ip) and wire speed (Ws). The research was investigated by material removal rate(MRR) (mm^3/min), surface roughness(SR) and surface crack density (SCD).

Table 1: Chemical Composition of Tungsten Carbide

Element%	O	C	W	Na	K	Total
Weight%	14.58	11.08	72.98	0.45	0.90	100

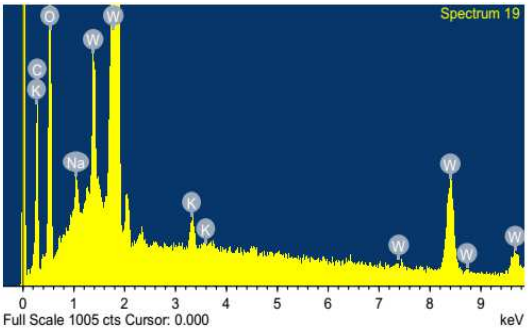


Figure 2: EDS Test of Tungsten Carbide

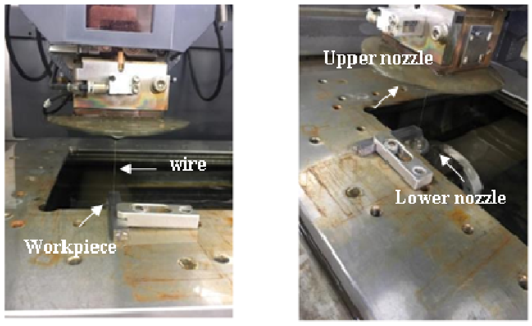


Figure 3: W-EDM Experimental Set up

2.2 Experimental Design by Taguchi Method

Taguchi design of experiment (DOE) has been used to investigate. In this experimental paper research for three parameters; voltage, current, level of configuration for each different level 3 as shown in the Table 2 format is a 3-level factor 3 trial by trial design can be in the form of a table storing the Taguchi is experimental results from L9 Orthogonal Array, as shown in the Table 2and ANOVA analysis the relative influence of processes parameters.

Table 2: Process Parameter Variable and their Levels

Factor	Sign	Unit	Level 1	Level 2	Level 3
Voltage Open	Vo	Volt	6	10	15
Peak current	Ip	Amp	5	7	8
Wire Speed	Ws	m/min	5	8	12

In order to ensure each of experimental data was conducted three times. In this research, L9 Orthogonal Array has utilized experimentation on wire EDM along with the result in termsmeans of response is present in Table 4.

2.3 Experimental Methodology

2.3.1 Material Removal Rate (MRR)

In this study, the effects of machining conditions on machining performance could be evaluated by MRR and surface quality represented the effect of discharge current on MRR. The results showed that the material removal rate significantly increased with the increase of the discharge current. The MRR can be obtained by the following equation(Arikatla et al., 2017)Vc: the average feed-in mm/min, H: The work piece thickness, k: Cutting width (offset) mm. land t is the cutting length in millimeter and time second respectively (Srinivasa Rao et al., 2016).

$$MRR = {}^{*}Vc \times H \times k \tag{1}$$

$$^{*}Vc = 60 \times {}^{l}/_{t} \tag{2}$$

2.3.2 Surface Crack Density

The surface crack density (SCD) are defined by the average crack length per area (µm/0.005 µm2). The crack length is measured after the WEDM process the result of SCD are investigated by SEM micrograph at 500 magnification. The length of cracks was measured on randomly selected three different sample areas of each W-ED Med machined surface area 13107.20(µm/µm2). Then the average crack length is divided by the micrograph to obtain the SCD follow the equation (3) below(Bhaumik et al., 2017; Mohanty et al., 2014).

$$\text{Surface crack density} = \frac{\mathbf{CL1 + CL2 + CL3}}{Area} \tag{3}$$

3. RESULTS AND DISCUSSIONS

3.1 Discharge Waveform of Analysis

The discharge energy of conventional WEDM at a current of 5, 7, 8A. The discharge process is controlled by WEDM-CNC program. The spark occurred in a gap between the wire tool and material. If the gap distance between electrode was too narrow, spark and concentrate wave amplitude would be occurred(Lin et al., 2014). The Figure 4a to Figure 4c: show, spark gap occurred. As mentioned above, the stability of WEDM processes can monitor and determined from inspecting the discharge waveforms. If the number of effective discharge waveforms moves up, the stability of the WEDM process is become better and then the machining efficiency will be increased. When the elapsed machining time is extended, more machining debris would be produced and suspended in the machining gap and wire breakage is ocurred. The debris accumulated also affect the WEDM progress due to the abnormal spark discharge (Lin et al., 2009; Zhou et al., 2018).

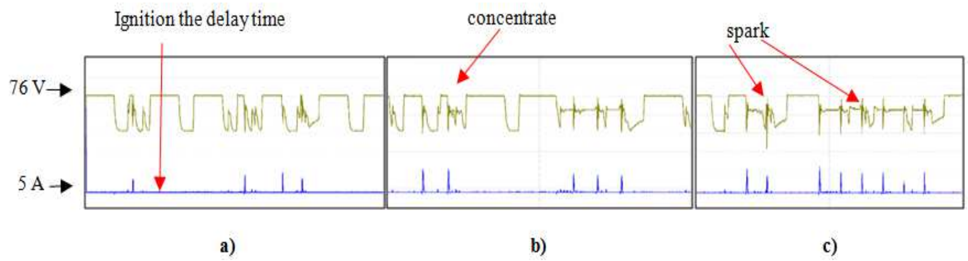


Figure 4: Discharge Voltage Waveform of Conventional WEDM; (a) Ip= 5 A, Ton=1, Toff= 18, (b) Ip= 7 A, Ton=1, Toff= 18, (c) Ip= 8 A, Ton=1, Toff= 18

3.2 Taguchi Method

Base on the Taguchi method, the signal to noise ratio (S/N ratio) was calculated from the optimal parameter value. Table 3 shows the experimental result and mean of Signal to Noise Ratios various result of the MRR, SR and Crack per design L9 orthogonal array. In this work the Minitab 18 was used to analysis value, "the higher is better" observed for MRR as following equations (4) and "the lower is better" observed for SR and Crack as following equations (5) (Ross, 1996).

$$\eta_{MRR} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} yi^{-2}\right] \tag{4}$$

$$\eta_{\text{Ra,Crack}} = -10\log\left[\frac{1}{\text{n}}\sum_{i=1}^{n} yi^2\right] \tag{5}$$

As a result main effect of the experimental parameter on MRR, SR and Crack shown the significance of parameter was present by the main effect of signal to noise (S/N ratios). The summaries of the parameter in each case are shown in Table 3. In this paper, the analysis of variance (ANOVA) was used to optimize the desired response to determine the priorities of the parameter for MRR, SR and crack integrity.(ANOVA) the result was investigated the 95% confidence level through MINITAB 18. The result obtained using the regression analysis for summarized significance process parameters, ie Vo, Ip, Ws are affected to MRR, SR, and surface crack density.

As a result main effect of experimental parameter level on MRR, SR and Crack the rank of S/N ratios of MRR, SR and Crack density from the Taguchi ranking response analysis the first rank shows the optimal for the main effect of the machined parameter the main effect of MRR as peak current (Ip) and voltage (V_O) is the main effect for surface roughness (SR) and surface crack density. This data the main effect was plot as shown in Figure 5 to Figure 7 respectively.

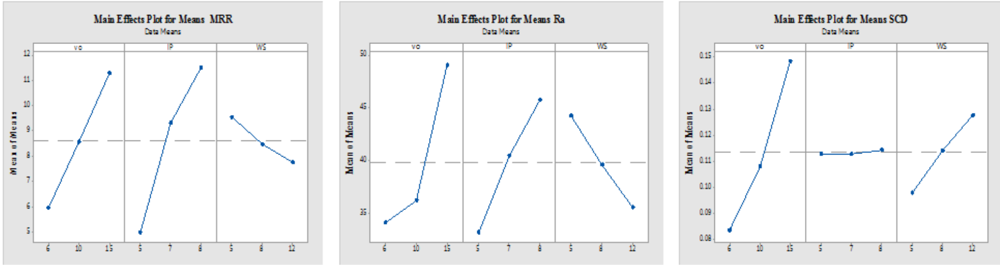
3.2.1 Effect of Process Parameters on MRR

The effect of WEDM parameter as shown the main plot of S/N ratio “The larger is better” was focused on material removal rate. Table 4 shows the effect of process parameters on MRR from ANOVA was performed and Figure 5a. shows the result of the main effect of the parameter on MRR according to Figure 5a. the MRR is highest at the third level of voltage open (15 volts), the third level of peak current (8 A) and the first level of wire speed (5 m/min). The material removal rate increase with voltage open and peak current increase and wire speed low. According to the main effect of MRR are optimal the average of a mean value, MRR increasing by peak current and voltage increase and on the other hand wire speed low this is due to high energy the discharge current lead to a high melting material and evaporation of the WC (Goswami et al., 2017; Rao et al., 2014).

Table 3: Experimental Result with Mean Responses and S/N Ratios of MRR, Surface Roughness and Crack Integrity

Exp. No.	Process Parameters			Mean of Responses			Mean of Main Effect Plot		
	Vo	Ip	Ws	MRR (mm^3/min)	SR (µm)	SCD (µm/mm^2)	Mean of MRR	Mean of SR	Mean of SCD
1	6	5	5	3.69	31.83	0.0698	3.2633	31.9489	0.067723
2	6	7	8	6.04	32.51	0.0836	6.5417	34.5656	0.083886
3	6	8	12	8.09	38.03	0.0972	8.0143	35.8556	0.098979
4	10	5	8	4.89	31.57	0.1065	4.8121	29.3956	0.108325
5	10	7	12	8.86	32.51	0.1239	8.4361	32.6289	0.121745
6	10	8	5	13.93	44.54	0.0932	12.4314	46.5956	0.093526
7	15	5	12	6.30	36.17	0.1620	6.8040	38.2256	0.162319
8	15	7	5	11.03	56.31	0.1306	12.9508	54.1356	0.132427
9	15	8	8	12.50	54.69	0.1524	14.0778	54.8089	0.150264

The result of the ANOVA is analysis process parameter it is observed that 95% confidence level the significant effect of the parameter when p-value less than 0.05. Table 4 present the result of ANOVA, it was observed the peak current is the major factor were significant parameter affected MRR, voltage and wire speed are respectively.



(a) (b) (c)

Figure 5: Main Effect of the Parameter on (a) MRR, (b) SR and (c) SCD

Table 4: Analysis of Variance for MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	113.973	37.9910	117.92	0.000
Vo	1	42.620	42.6197	132.29	0.000*
Ip	1	66.630	66.6295	206.81	0.000*
Ws	1	4.724	4.7237	14.66	0.012*
Error	5	1.611	0.3222		
Total	**8**	**115.584**			
S = 0.567602	R-sq = 98.61%		R-sq(adj) = 97.77%	R-sq(pred) = 94.89%	

*significant

3.2.2 Effect of Process Parameter on Surface Roughness

“Smaller is better” the characteristic of as a variable in the analysis of surface roughness (SR). The surface roughness was measured by using roughness tester; TIME series TR200 as the result shows the effect of process parameters on SR from ANOVA was performed in Table 5 and Figure 5b. shows the main effect of SR. according to Figure 5b. the lowest at the first level of voltage open, peak current and third level of wire speed. It can be observed that SR increased with Voltage and peak currently increased and decrease with wire speed. With the peak current increase and voltage has raised the density of discharge current were erode and melting materials on the surface the mechanism of voltage and peak current each pulse on time is eject and explode the material from work piece lead to the deep hole, crater, coral reef, micro-void and crack density.(Goyal, 2017)The surface roughness depends on the size of the crater, coral reef (Saha, Singha, Pal, & Saha, 2007) as a result is shown by SEM micrograph in Figure6 to Figure 7.

The SEM photograph was observed by Scanning electron microscope SEM (JEOL700) for SR and density of surface crack Figure 6a. shows the lower is better of characteristic by machine parameter. This pic as shown the main effect on Ra and crack is smallest on voltage 10 volt, the peak current 5 and wire speed 8 m/min it contributed 31.57 µm at the same condition the surface crack density increased with wire speed is increased the value in this experiment No.4 is 4.89 mm3/min in MRR and 0.1065 µm/mm2 in SCD and Figure6b. shows the highest of surface and SCD after wire machine process and the assessment of a result show the effect of peak current, voltage and wire speed are affected to the formation of the surface at 56.31 µm of SR in experiment No.8 and the experiment No.7 observed value is 0.1620 of SCD the main effect of the input parameter, the influence of the most significant on SCD.

Figure 6c shown the cracks of work pieces that leads to spotting with a scanning electron microscope (Electron Microscope Scanning: SEM) found that the majority of work piece surface layer melting occurs at the surface area because when the work piece has been through the cutting power by using a wire (Wire cut EDM) already.

The roughness of surface and density of crack increased when the electrical discharge increase because the thermal conductivity allowed a rapid dissipation of the heat through the sample instead of being concentrated on the surface, causing larger discharge energy on the surface and producing deeps melting and larger craters which induced surface roughness on the work piece. Due to the smooth of the surface are assessed by SEM the Figure 7. from the investigate experiment No. 9 shown the particles of debris granule and coral reef are mitigating respectively.

The surface crack on tungsten carbide likely occur at wire electrical discharge process can explain the thermal stress after machine cooling down term of surface stress occur and WC is obtain a carbide phase sintering as a result to boundary gain crack due to reduce the surface roughness integrity (Bonny et al., 2009).

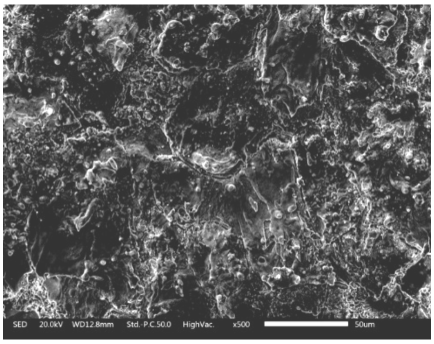


Figure 6(a): SEM Characteristic of SR (Exp. No. 4)

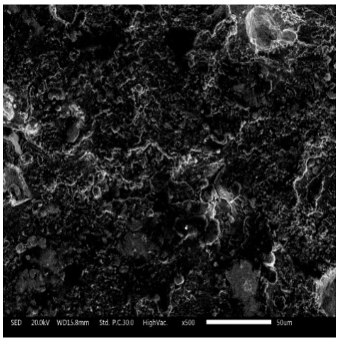


Figure 6(b): SEM Characteristic of SR (Exp. No. 8)

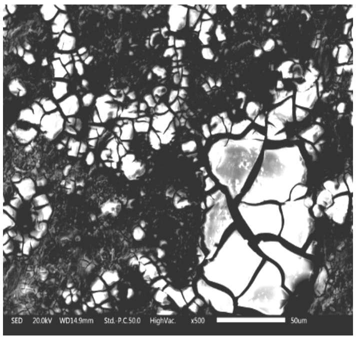


Figure 6(c): SEM Characteristic of SR and SCD (Exp. No. 9)

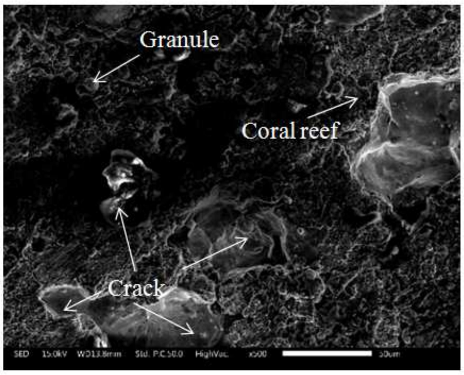


Figure 7: SEM Photograph of the Characteristic Surface Work Piece

The result of the ANOVA for the resulting minimum 95% confidence interval of surface roughness as shown in Table 5. It was observed that the major factor for surface roughness is voltage, peak current and wire speed respectively.

Table 5: Analysis of Variance for Surface Roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	698.27	232.76	16.09	0.005
Vo	1	351.16	351.16	24.27	0.004*
Ip	1	236.22	236.22	16.33	0.010*
Ws	1	110.89	110.89	7.66	0.039*
Error	5	72.34	14.47		
Total	**8**	**770.61**			
S = 3.80368	R-sq = 90.61%		R-sq(adj) = 84.98%		R-sq(pred) = 65.30%

*significant

3.2.3 Effect of Process Parameter on the Density of Surface Crack

The crack integrity was evaluated as “smaller is better”. From Figure 5c, analysis of variance for surface crack density (SCD) was shown in Table 6. The main effect plot is voltage open following by peak current and wire speed respectively. The reason can be explained that more discharge energy causes more melting, evaporation and erosion of work piece. The lower voltage, current and wire speed cause small gap and lack of flushing lead to re-solidify on surface rapidly occur upon to generate crack on grain bound of material (Saha et al., 2007) which affect to crack density on surface material (Goswami et al., 2017). The melting and re-solidification of material caused the formation of surface the surface crack was observed to the difference of thermal hence more volume the stress level on the surface lead to shift and crack on the work piece.(Srinivasa Rao et al., 2016)

The relatively significant of individual factors for the WEDM process, MRR, SR, SCD have been found that by Minitab 18. The optimal of parameters to the processing set up to investigate MRR, SR, and SCD given in Table 7 as shown the predicted optimal value and confirm the experimental result for each condition response.

Table 6: Analysis of Variance for SCD

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.007703	0.002568	142.62	0.000
Vo	1	0.006390	0.006390	354.94	0.000
Ip	1	0.000002	0.000002	0.13	0.731
Ws	1	0.001311	0.001311	72.79	0.000
Error	5	0.000090	0.000018		
Total	**8**	**0.007793**			
S = 0.0042431	R-sq = 98.84%		R-sq(adj) = 98.15%		R-sq(pred) = 96.50%

*significant

Table 7: Confirmatory Experimental Results

Response	Optimal Condition	Experimental	Predicted Optimal Value	95% CI
MRR	15Vo8Ip8Ws	12.50	15Vo8 Ip5Ws	14.0031< MRR< 16.2000
SR	10Vo5 Ip8Ws	31.57	6Vo5 Ip12Ws	13.2557< SR< 28.9625
SCD	6Vo5 Ip5Ws	0.069	6Vo5 Ip5Ws	0.0586<SCD< 0.0757

4. CONCLUSIONS

The significant concentrates of input factor for determining of WEDM process on tungsten carbide for observed the MRR, SR, SCD has been investigated by Taguchi technic to optimize optimal condition for the trim cut on wire electrical discharge machine process. For the main conclusion as follows

- The most significant factor for MRR is peak current following by voltage and wire speed.
- The most significant factor for surface roughness is voltage following by peak current and wire speed.
- The most significant factor for surface crack density is voltage and wire speed respectively.

5. ACKNOWLEDGEMENTS

The authors are would like to thank the Thammasat University, Faculty of Engineering and Research administration division; for financial support. The author would like to thank the at National and Metal and Materials Technology Centre (MTEC) for their technical and equipment supported in research.

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